UNITED STATES PATENT APPLICATION

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for

PROCESS FOR MAKING A SHEET OF ARAMID FIBERS USING A FOAMED MEDIUM

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CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 60/409,231, filed on September 10, 2002, the entirety of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a process for forming a nonwoven sheet of composite aramid fibers, and aramid fibrid, using a foam furnish. More specifically, the present invention relates to an efficient foam process for making a uniform sheet of aramid fibers, also containing aramid fibrid.

Description of the Related Art

The use of foam in a furnish for preparing wet-laid, non-woven fibrous webs is known. See, for example, U.S. Patent No. 4,443,297, which discloses an apparatus and method for the manufacture of a non-woven fibrous web using foam. The method involves preparing a foam furnish with 55-75% volume air, recirculating a surfactant-water solution through a forming wire followed by foam storage in a silo to eliminate excess air, and then recycling foam from the bottom of the silo. See also, U.S. Patent Nos. 4,349,414; 4,443,299; 4,498,956; and 4,543,156.

U.S. Patent No. 4,488,932 relates to a method of manufacturing fibrous webs of enhanced bulk. The method involves hammermilling dry hydrophilic fibers to generate crimp, and then foam forming these fibers in 0.5 to 5 minutes to retain as much crimp as possible.

U.S. Patent No. 4,686,006 relates to an apparatus and method for laying down a fibrous web from a foam-fiber furnish. A headbox is used which includes walls defining an elongate channel extending transversely of the direction of movement of the forming wire. Foam forming nozzles are positioned to introduce foam-fiber furnish into the channel for turbulence, inducing impact on an oppositely disposed wall defining the channel. The turbulently flowing foam-fiber furnish is then introduced to the headbox slice for discharge onto the forming wire with minimized orientation of the fibers.

Other patents which relate to the use of foam in making non-woven fibrous webs include U.S. Patent Nos. 3,716,449; 3,938,782; 3,871,952; 3,837,999; 3,876,498; 3,846,232; 4,062,721; 3,746,613, 4,056,456; 5,720,851; 5,904,809; 6,238,518 and 6,258,203.

Sheets of aramid fibers have been made. However, the formed sheets lack uniformly and the processes are inefficient. Moreover, the use of longer aramid fibers, e.g., longer than 0.25 inch, is desirable. Improved uniformity of dispersion and distribution of the aramid fibers in the web would be a great step forward in the art, as would increased ease and efficiency in forming the web, particularly when employing longer aramid fibers. Such sheets also containing

aramid fibrid would be of great value. Techniques useful in the formation of more uniform non-woven webs made of longer aramid fibers would be of great benefit to the industry as such aramid fiber sheets have many potential uses, particularly when the sheet further contains aramid fibrid.

Accordingly, it is an object of the present invention to provide a novel process for forming a non-woven fibrous web of aramid fibers and aramid fibrid using foam, which process provides a web in which the fibers are uniformly and evenly distributed, and the web/sheet displays great integrity.

This and other objects and features of the invention will become apparent to one skilled in the art upon a review of the following description, the figures of the drawing, and the claims.

SUMMARY OF THE INVENTION

Provided by the present invention is an effective and efficient method for preparing a non-woven fibrous web of aramid fibers using a foam furnish, which foam furnish is prepared by using the specific agitating means of the present invention. The web preferably also comprises aramid fibrid, which can improve the integrity of the sheet.

The apparatus used for agitating the long aramid fibers in a foamed medium comprises agitating means mounted for displacement within a foamed medium and includes a leading surface facing in a direction of displacement, the leading surface including upper and lower portions converging in the direction of

displacement to form a generally convex leading surface. The trailing surface is concave. The abrupt transition between the two surface shapes leads to cavitation or bubble formation. The apparatus further comprises driving means for displacing the agitating means in the direction of displacement for dispersing and mutually separating the aramid fibers within the foamed medium.

More specifically, the apparatus for agitating the fibers in a foamed medium comprises a tank having a cylindrical surface forming an agitating chamber for containing a mixture of lengthy aramid fibers, aramid fibrid and foamed medium, which can include other functional additives. The agitating means is mounted for rotation about an upright axis coinciding with a longitudinal axis of the agitating chamber and including a plurality of legs projecting generally radially from the axis, each leg including a leading surface facing in a direction of rotation and terminating in upper and lower trailing ends, said leading surface including upper and lower portions which converge in the direction of rotation to form a generally convex leading surface. The apparatus further comprises driving means for rotating the agitating means to disperse and mutually separate the aramid fibers within the foamed medium, the agitating means forming a central agitation zone, the ratio of the diameter of the agitation zone to the diameter of the agitating chamber being from about 0.5 to about 0.95.

Thus, by the present invention there is provided a method for forming a non-woven, fibrous web composed of aramid fibers, and preferably aramid fibrid, which comprises first forming a foam furnish by agitating the aramid fibers

(and preferably aramid fibrid) in a foamed medium, preferably aqueous, with the agitating means of the present invention. The resulting foam furnish is then passed onto a screen and defoamed using conventional techniques.

In another embodiment of the present invention there is provided a non-woven fibrous web comprised of very long aramid fibers, in combination with aramid fibrid, prepared by the method of the present invention. The web exhibits excellent uniformity, i.e., very few fiber bundles, and substantially no fiber directionality.

BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWINGS

FIG. 1 is a side view of an agitating apparatus of the present invention.

FIG 2. is a top view of an agitating apparatus of the present invention.

FIGS. 3-5 are side and end views of the agitator.

FIGS. 6-11 depict various acceptable shapes of the agitator legs.

FIG. 12 is a top view of a four-legged agitator of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The process of the present invention comprises the steps of first forming a foam furnish by agitating a fiber mixture comprised of up to 100% of aramid fibers, in a foamed medium with the agitation apparatus of the present invention, and then passing the foam furnish onto a screen, e.g., a wire or plastic fabricated screen, and defoaming the furnish. Preferably, the furnish will also

contain aramid fibrid. The aramid fibrid is a small irregularly shaped piece of aramid, e.g., Nomex®, polymer that is much larger in two dimensions than it is in the third dimension. It is like a microscopic corn flake in shape. The large dimensions are on the order of 5 to 25 micrometers, while the third and smaller dimension is about 0.01 to 1 micrometer. The fibrid can serve as a bonding agent for the aramid fibers in the final web, and thus greatly enhances the integrity of the final web. The agitating apparatus used in the process is depicted in the Figures of the Drawing, and can be described by reference thereto.

The agitating apparatus 10 shown in FIGS. 1-3 comprises a tank 12 having an internal cylindrical surface 14 forming a cylindrical agitating chamber 16 which receives the mixture of fibers, surfactant, and water. The mixture is agitated by an agitator 18 which causes the surfactant and water to form a foamed medium in which the aramid fibers are entrained. In particular, the agitator serves to keep the aramid fibers in a dispersed, mutually separated condition within the foamed medium, as will be hereinafter explained.

The agitator 18 is rotatable about a vertically upright axis A which coincides with the longitudinal axis of the cylindrical agitating chamber 16. The agitator is fixedly connected to the lower end of a vertical shaft 20 which is rotatably displaced by a motor 22 connected to an upper end of the shaft 20 in any suitable manner, such as by a pulley and belt connection represented by phantom lines.

The agitator 18 comprises a plurality of legs or blades 24 projecting radially from the axis A. The number of legs 24 may vary, there being two legs 24 shown in FIGS. 1 and 2. An alternative embodiment of the agitator 18A shown in FIG. 12 has four legs 24A. There could be other numbers of legs, e.g., three equally circumferentially spaced legs (not shown). The legs 24 shown in FIG. 1 are disposed in the same horizontal plane. Alternatively, the legs could be disposed in different planes. For example, if four legs 24A were used as shown in FIG. 12, they could be arranged in two pairs disposed in vertically spaced planes.

Each leg includes a leading surface 26 facing in the direction of rotational displacement R (see FIGS. 2 and 6). That surface is of convex shape as the leg is viewed in cross section (see FIGS. 4 and 5). By convex is meant that the upper and lower portions of the leading surface converge in the direction of rotation R and meet at a relatively blunt junction. The bluntness of the junction precludes the collection of fibers. It is also preferred that the leading surface be smooth so that fibers can slip over its surface without forming flocs, spindles, or other forms of fiber aggregates.

Various preferred convex configurations of the leading surface are depicted in FIGS. 6 and 11 and will be discussed hereinafter.

The leading surface 26 terminates in vertically spaced upper and lower trailing ends 28, 30 which form edges 32, 34, respectively. The trailing surface 36 of the leg 24, which surface faces away from the direction of rotation, is non-convex, e.g., concave in Fig. 6.

The legs 24 are formed by a hollow cylindrical bar 40. The axis A bisects the bar to form two bar sections disposed on opposite sides of the axis A. The portion of each bar section which faces away from the direction of rotation is truncated in that the trailing portion of the bar is cut along a plane C extending through the center of the bar (see FIG. 6). The truncation of a hollow cylinder represents a convenient way of forming the agitator, but, of course, other techniques could be used to form an agitator of the desired shape.

As the agitator rotates, it creates a circular agitation zone Z in the center of the agitation chamber or tank 16 (see FIG. 2). The ratio of the diameter d of that agitation zone to the diameter of the agitation chamber 16 (i.e., d/D) is preferably from about 0.5 to about 0.95, more preferably from about 0.65 to about 0.80; and most preferably from about 0.67 to about 0.75.

Rotation of the agitator 18 is initiated after the mixture of aramid fibers, water, and surfactant is placed within the agitation chamber. Other functional additives can be added, if desired. It is also preferred that aramid fibrid be added to become part of the foam furnish and ultimately the final web. In response to that rotation, the surfactant and water produce a foamed medium in which the fibers are entrained. As the agitator 18 travels through the mixture, fibers impacted by the agitator are displaced upwardly or downwardly by the convex leading surface 26.

The convex leading surface of the agitator and the trailing concave following edge are important to the proper function of the apparatus. Fibers are

impacted by the leading convex surface. This surface is made to be smooth so that the aramid fibers will slide along this surface without forming multi-fiber aggregates. As the aramid fibers leave this smooth convex surface they enter the abrupt transition to a concave surface. Intense cavitation occurs at this transition. Air pulled into this zone from the tank vortex or air added to the tank from some other source such as a pipe at the bottom, forms a foam which is stabilized by the presence of a surfactant which has been added to the water. This foam is characterized by small bubble size. Thus the aramid fibers entering this zone of bubble formation are immediately surrounded by foam. Since the foam possesses a high viscosity and low density, the aramid fibers surrounded by foam are prevented from tangling or flocculating as would be the case if they were in water. This apparatus is unique in its ability to disperse aramid fiber into a foam uniformly.

The entire mixture of fibers and foamed medium, preferably also containing the aramid fibrid, tends to swirl within the agitation chamber 16. It has been found preferably to provide a plurality of baffles 42 projecting radially inwardly from the surface 14 of the agitation chamber 16 in order to deflect the swirling mixture inwardly from the surface 14. This prevents the aramid fibers from accumulating at the surface 14 due to centrifugal force. The baffles are preferably plate-shaped and disposed diametrically apart. The number of baffles may vary. It has been found advantageous to provide four baffles when a two-legged agitator (FIG. 1) is used; to provide three or six baffles when a three

legged agitator (not shown) is used; to provide four or eight baffles when a four-legged agitator (FIG. 12) is used.

In the case of three baffles, they would preferably be located at the same elevation and spaced apart circumferentially equidistantly.

In the case of four baffles, they would be arranged as two pieces of diametrically opposed baffles. The baffles can be equally circumferentially spaced, or vertically spaced.

The lower pair of baffles could be vertically aligned with respect to the upper pair of baffles, or they could be circumferentially offset therefrom.

As pointed out earlier, the shape of the agitator legs can assume various forms. For example, as shown in FIG. 7 the agitator 18A could be formed of a segment of a cylinder, as in the case with the earlier described agitator 18. However, the truncation of the cylinder would occur rearwardly of the center of the bar to form the trailing edges 32A, 34A.

The agitator 18B depicted in FIG. 8 is similar to that of FIG. 6, but the upper and lower trailing ends of the agitator are beveled to form sharper trailing edges 32B, 34B.

In FIG. 9, an agitator 18C is depicted in which the leading convex surface 26C and the trailing concave surface 36C are of oblong or elliptical shape in cross-section.

In FIG. 10, an agitator 18D is depicted in which the leading surface 26D is the same as in FIG. 6, but wherein the trailing surface 36D is flat.

An agitator 18E depicted in FIG. 11 has a convex leading surface 26D comprised of two flat portions 50 which converge in the direction of rotation, and which meet at a curved (blunt) junction 52.

The agitation is generally conducted such that the foam furnish created has an air content of at least 50% by volume, and more preferably an air content of at least 75% by volume.

The aramid fibers agitated can be any aramid fiber, having any length. Commercially available aramid fibers are sold under the Trademarks Nomex® and Kevlar®. The present invention is uniquely applicable to very long aramid fibers. One of the important advantages of the present invention is that excellent webs of long aramid fibers can be easily handled and formed into an excellent web. The fiber mixture can comprise up to 100% aramid fibers, or the mixture can also comprise cellulosic, non-cellulosic or synthetic fibers. It is generally preferred that the mixture contain at least 50% by weight long aramid fibers.

Preferably, the mixture also comprises aramid fibrid, which can act as a binder. However, due to the length of the aramid fibers of the present invention, less aramid fibrid may be needed as found in conventional aramid papers. A great advantage of the present invention, however, is that the use of the foam medium provides an excellent web of aramid fibers and aramid fibrid distributed therethrough, thus allowing the fibrid to advantageously act as a binder and provide integrity throughout the entire web.

While the length of the aramid fibers used can be of any length, the present invention is most uniquely and advantageously applicable to long fibers, i.e., greater than ¼ inch and at least ½ inch. Aramid fibers of a length of one inch, one and one-half inch, two inches or more, even three or four inches in length, can be readily incorporated into a non-woven fibrous web using the present agitator and foam process.

The amount of aramid fibrid generally employed as a binder can be substantially reduced as the length of fiber is increased. For example, conventional aramid papers comprise 60% fiber and 40% fibrid. In the papers of the present invention, 30% fibrid and less can be used. More specifically, 25% fibrid or less is preferred, with as low as 15% or even 10% fibrid still allows for a nonwoven aramid web of good strength.

As noted above, the present invention is uniquely applicable to the formation of a non-woven fibrous web comprised of aramid fibers, which can be in mixture with other fibers, such as cellulosic, synthetic or metal fibers. Any synthetic, i.e., polymeric, fiber can be used. Examples include polyester, aramid, polyamide, and polyolefin fibers. The aramid fibers can also be used alone or in combination with metal fibers such as stainless steel, zinc, inorganic and/or nickel fibers. Mixtures of cellulosic (wood) and synthetic or other non-cellulosic fibers can also be used in combination with the aramid fibers.

The consistency of the foam furnish created, i.e., the percentage solids in the foam furnish, is generally in the range of from 0.2 to 2.0 wt %, and is

preferably about 0.5 wt % or greater. A consistency of greater than 0.5% yields a product having a very high basis weight. A consistency of 1.0 wt % or more has heretofore been unusable, and therefore the present invention permits one to operate at much higher consistencies than are conventional, if it is so desired. An important advantage of being able to use a high consistency is that much less process solution or foam needs to be handled. Inclined wire markers can generally handle 0.5 inch fibers at a consistency of 0.05%, thereby requiring, however, 10X as much process solution or foam. The process of the present invention allows one to handle long aramid fibers at very high consistency and thereby enjoy the advantages and benefits thereof.

The agitator width to fiber length ratio is preferably at least about 1.25, more preferably at least 1.75, even more preferably at least 2.5 and most preferably at least 3.0. These higher ratios are preferred because they more consistently provide the best formed and most uniform non-woven web products independently of the other variables, such as the RPM of the agitator.

The foamed medium in which the aramid fibers are agitated can be formed during the agitation, or can be formed prior to the agitation of the fibers. When forming the foamed medium in situ, the order of addition of water, chemicals (binder), surfactant and fiber is not important. The surfactant, water and aramid fiber can be added into the mixing chamber in any order. Once the agitator is started, a successful foam dispersed aramid fiber will result. It is generally preferred, however, to not mix the fibers in the water without the

presence of a surfactant. Since no foam would be generated without the surfactant, the aramid fibers would tend to tangle and agglomerate. It is possible, however, to successfully disperse the aramid fibers in a pre-existing foam.

The concentration of the surfactant depends on the surfactant. Generally, a concentration of about 0.1 wt % in the solution is preferred for a strong foam forming surfactant. If the surfactant is a weaker foam former, a stronger concentration may be preferred. Anionic, non-ionic and cationic surfactants can all be used, with appropriate adjustments in concentration where needed.

The time the foam furnish is mixed by the agitator of the present invention can vary greatly, as it is only important that a good dispersion of the fiber in the foam is achieved. Once a good dispersion has been achieved, longer mixing or agitation is generally neither helpful or harmful.

The temperature of the foam furnish can also vary greatly. The temperature need only be such so as to allow a foam to be generated.

Other conventional, functional additives can also be added to the foam furnish, as long as they do not interfere with the foaming nature of the surfactant. Polymeric binders can be added. For example, polyvinyl alcohol powder has provided good results, and is a preferred additive. The presence of the fibrid, however, greatly lessens the need for polymeric binders.

Once the foam furnish has been made, the foam furnish is then passed onto a screen, such as that generally used in a typical Foudrinier machine. The

foam furnish is then defoamed by using vacuum or suction boxes. Alternatively, the foam furnish could be deposited on a screen using a pressure former. Any of the conventional methods and apparatus for forming a fibrous web while using a foam can be employed with the foam furnish of the present invention. The use of the agitation means of the present invention provides a foam furnish with a uniform dispersion of the fibers. As a result, the fibrous web obtained upon defoaming is a web exhibiting good individual fiber separation and a very uniform distribution. As well, there is controlled directionality of the fibers depending on the design of the headbox.

Such a uniform fibrous web is obtained even when one employs very long fibers, such as fibers having a length of one-half inch, one inch, two inches or longer, and even if cellulosic, synthetic, refractory, or metal fibers are mixed with the aramid fibers. A great advantage of the present invention is that it permits one to make a fibrous web comprised of long aramid fibers, if desired, in combination with other types of fibers, as easily and as quickly as one could make a paper web. The presence of the aramid fibrid also improves the integrity of the product and is easily and effectively integrated into the web using the process of the present invention.

The uniform, non-woven webs prepared in accordance with the present invention, employing aramid fibers, can find many useful applications, particularly for high temperature insulation, e.g., in a transformer. Other applications would include diffusion layers in fuel cells and battery membranes. It is the uniformity

of the non-woven web achieved through the practice of the present invention, and the use of fibrid to enhance integrity and consistency, which allows the webs of the present invention to be successfully applied.

While the invention has been described with preferred embodiments, it is to be understood that variations and modifications may be resorted to as will be apparent to those skilled in the art. Such variations and modifications are to be considered within the purview and the scope of the claims appended hereto.